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Safety culture: a survey of the state-of-the-art

J.N. Sorensen[1]

Advisory Committee on Reactor Safeguards, US Nuclear Regulatory Commission, Mail Stop 013 D13, Washington, DC 20555-0001, USA

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Abstract

This paper discusses the evolution of the term 'safety culture' and the perceived relationship between safety culture and safety of operations in nuclear power generation and other hazardous technologies. There is a widespread belief that safety culture is an important contributor to safety of operations. Empirical evidence that safety culture and other management and organizational factors influence operational safety is more readily available for the chemical process industry than for nuclear power plant operations. The commonly accepted attributes of safety culture include good organizational communications, good organizational learning, and senior management commitment to safety. Safety culture may be particularly important in reducing latent errors in complex, well-defended systems. The role of regulatory bodies in fostering strong safety cultures remains unclear, and additional work is required to define the essential attributes of safety culture and to identify reliable performance indicators. Published by Elsevier Science Ltd.

Keywords: Safety culture; Human reliability; Safety regulation

1. Introduction

The nuclear industry and the US Nuclear Regulatory Commission (NRC) explicitly recognized the importance of management and organizational factors to nuclear facility safety in the aftermath of the accident at Three Mile Island (TMI) Unit 2. Following the Chernobyl accident, the International Nuclear Safety Advisory Group (INSAG) introduced the term 'safety culture' to denote the management and organization factors that are important to safety [1]. Although INSAG intends 'safety culture' to capture all the management and organizational factors relevant to safe plant operation, many investigators use the term more narrowly. 'Safety culture' is often used to denote an element of organizational culture, that, in turn, is a component of the broader term 'management and organizational factors.'

Although major accidents often involve an unsafe act (or failure to act) by an individual, they may also involve conditions created by an organization that can magnify the consequences. The NRC's investigation of the accident at TMI reported to the Commissioners and the public that, "The one theme that runs through the conclusions we have reached is that the principal deficiencies in commercial reactor safety today are not hardware problems, they are management problems [2]." Later the report stated, "The NRC, for its part, has virtually ignored the critical areas of operator training, human factors engineering, utility management and technical qualifications." That sentence captures the basis for much of the NRC's regulatory agenda in the years following the accident, as well as the industry's agenda to improve plant operations.

The NRC's post-TMI action plan included a large number of issues under the general heading of human factors. The major categories included operator qualifications and training, staffing levels and working conditions, the man–machine interface, emergency operating procedures, human reliability, and organizational and management effectiveness.

Independent of the initiatives that the NRC undertook, the industry saw a need to improve the quality of nuclear operations. The Institute of Nuclear Power Operations was established by the electric utilities that owned and operated nuclear power plants to foster excellence in plant operations.

Confidence in facility management and human performance within the international nuclear power community was severely damaged by the Chernobyl accident in 1986. In its report of the Chernobyl post-accident review meeting [1], INSAG stated that, "The vital conclusion drawn is the importance of placing complete authority and responsibility for the safety of the plant on a senior member of the

E-mail address: jns@nrc.gov (J.N. Sorensen).

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operational staff of the plant. Formal procedures, properly reviewed and approved, must be supplemented by the creation and maintenance of a 'nuclear safety culture.'"

The present paper explores the nature of safety culture and its perceived importance in the management and regulation of hazardous technologies. Its purpose is to provide a tutorial, for non-practitioners of the human performance disciplines, that addresses the following questions:

- What is safety culture?
- How can it be measured?
- How is safety culture related to safety of operations?
- How is safety culture related to the regulatory process?

Note that addressing these questions does not imply a promise to provide answers to all of them. As one investigator observed, "...the sheer multiplicity of constituent elements of a safety culture and its precept of universal involvement imply that any attempt to monitor its health... is bound to be complex... [3]."

Because the term 'safety culture' was introduced by INSAG, we first look at INSAG's development of the idea, and the structure it designed for evaluation and implementation. Next, we consider the intellectual foundation of the concept, independent of the INSAG construct. We then discuss the larger issue of human performance, and the place of safety culture within that context. Since the ultimate objective is to establish a relationship between safety culture and the safety of facility operations, we next define the steps required to demonstrate such a link, and review some of the work that has been published toward that end. Finally, we look at the relationship between safety culture and the regulatory process, and identify areas where additional work would appear to be beneficial.

2. Evolution of the term 'safety culture'

Having introduced the term 'safety culture' into the nuclear safety discussion, INSAG expanded on its importance in INSAG-3 [4], explaining that "The phrase 'safety culture' refers to a very general matter, the personal dedication and accountability of all individuals engaged in any activity which has a bearing on the safety of nuclear power plants." INSAG-4 [5] develops the concept of safety culture in considerable detail, observing, "...the meaning of the term [in INSAG-1 and INSAG-3] was left open to interpretation and guidance was lacking on how Safety Culture could be assessed."

INSAG-4 defines safety culture as: "...that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance." It then explains that, "Safety Culture is attitudinal as well as structural, relates both to organizations and individuals, and concerns the requirements to match all safety issues with appropriate perceptions and action."

Since the definition of safety culture is related to personal attitudes and habits of thought and to the style of organizations, INSAG-4 suggests that, "...such matters are generally intangible; that nevertheless such qualities lead to tangible manifestations; and that a principal requirement is the development of means to use the tangible manifestations to test what is underlying." Arguing that "...sound procedures and good practices are not fully adequate if merely practiced mechanically...," INSAG-4 holds that "...Safety Culture requires all duties important to safety to be carried out correctly, with alertness, due thought and full knowledge, sound judgment and a proper sense of accountability."

The body of INSAG-4 is devoted to articulating what it terms universal features of a safety culture and the identification of broad characteristics (tangible evidence) of an effective safety culture. The approach to both topics, universal features and tangible evidence, is to provide detailed lists of the desired attributes.

Within the operating organization, INSAG looks first at the corporate policy level: "Safety Culture flows down from actions by the senior management of an organization.... The primary indication of corporate level commitment to Safety Culture is its statement of safety policy and objectives." Other indicators of safety culture should be found in regular reviews of the organization's safety performance and the evaluation of individual attitudes toward safety as part of the staff selection and promotion process.

To find tangible evidence of safety culture among the operating personnel of a particular power plant, INSAG suggests that the three aspects to be considered are (1) the environment created by local management, (2) the attitudes of individuals at all levels, and (3) the actual safety experience at the plant. The working environment should include defined safety responsibilities and detailed practices at all levels. Training and education should ensure staff knowledge about possible errors in each individual's area of activity. Safety concerns should be given a high level of visibility by plant inspections, audits, visits by senior officers, and safety seminars. Satisfactory facilities, including tools, equipment and information, should be provided to the staff.

Individual attitudes are reflected by adherence to procedures, stopping to think when facing an unforeseen situation, and management respect for a good safety attitude. Managers should take opportunities to show that they will put safety concerns ahead of power production if circumstances warrant. Development of local practices for enhancing safety, such as error reporting, should be encouraged.

Ultimately, in INSAG's view, the effectiveness of the organization's safety culture should be reflected in the performance of the facility. Plant performance indicators, including plant availability, number of unplanned shutdowns, or radiation exposure, are a reflection of attention to safety. Significant events that occur should be analyzed to determine what they reveal about staff strengths and weaknesses. The rigor of the reviews, and the effectiveness of any resulting corrective actions, are important safety culture indicators.

INSAG-4's conclusion is that safety culture is now a commonly used term, and that it is important to give practical value to the concept. This includes identifying attributes that may be used to judge the strength of safety culture in specific instances. An appendix is included that identifies 143 questions INSAG suggests are worth examining when the effectiveness of safety culture is to be judged in a particular situation.

Following the publication of INSAG-4, the International Atomic Energy Agency (IAEA) published guidelines [6] "... for use by any organization wishing to conduct a self-assessment of safety culture." Titled "ASCOT Guidelines," (Assessment of Safety Culture in Organizations Team Guidelines), the document summarizes the concept of safety culture and then describes a process for assessing safety culture. The ASCOT guidelines restate the basic INSAG questions and then expand on them with approximately 300 'Guide Questions.'

Missing from the ASCOT guidelines, as well as from INSAG-4, is any indication of how an overall conclusion should be drawn from the collected answers to all the questions. Possibly, the intent of judging safety culture does not include an overall conclusion. It may be that in each area the intent is simply to identify deficiencies and make suggestions for improvements in those areas. Still, it would seem that a facility with a poor safety culture might be left with an overwhelming list of corrective actions. Unless some guidance is provided on how to proceed, the evaluation may provide little help. It would seem inevitable that the review team will conclude that a safety culture is superior, acceptable, or deficient, and attempt to provide the proper degree of motivation for corrective actions. The ASCOT guidelines do not appear to help in the formulation of overall conclusions.

The fundamental problem with INSAG's approach to safety culture is that it specifies in great detail what should be included, but provides little guidance on overall criteria for acceptability. Furthermore, no link is made (or even seems possible) between safety culture as INSAG defines it and human performance or human reliability. A positive relationship is simply assumed. One of the goals to be reached in risk informed regulation is to advance the state of the art in probabilistic risk assessment (PRA) to account for the probability of human error, and to further account for the contribution of human skills to recovering from accident sequences. The INSAG approach appears to make little contribution to either. It is also true that the INSAG work does not establish the link between a good safety culture and safe plant performance. The relationship is, again, simply assumed. While it seems plausible that the sum total of the indicators of a strong safety culture would imply safe plant operations, that is not the same as demonstrating a cause and effect relationship. The possibility remains that safe plant operations can be fostered, perhaps even more effectively, by other organizational characteristics.

3. Organizational culture

Although INSAG has borrowed the term 'culture' from either anthropologists or the organizational development community (who in turn borrowed it from anthropologists), the INSAG publications make no reference to the bodies of literature in those fields. In fact, no attempt is made to link 'safety culture' with 'culture' as the term is used elsewhere. Nevertheless, suggestions that 'culture' might help explain organizational behavior, and that management and organizational factors could influence safety performance, both predated INSAG's introduction of the term 'safety culture.'

Ostram et al. [7], note that "Heinrich's Domino Theory developed in the 1930s was based on the premise that a social environment conducive to accidents was the first of five dominos to fall in an accident sequence." Deal and Kennedy [8] attempted to establish why the structure of an organization often did not explain the control of work activities, and suggested culture as the undocumented influence. Uttal [9], after several books had been published on the human underpinnings of business, summarized the meaning of organizational culture as: a system of shared values (what is important) and beliefs (how things work) that interact with a company's people, organizational structures, and control systems to produce behavioral norms (the way we do things around here).

Bridges [10] raises a cautionary note regarding the current practice of assuming an organizational culture exists, can be reasonably well defined, and can be changed. He observed that there are several important differences between 'culture' as commonly used by anthropologists and 'culture' as applied to organizations by management consultants. He noted that, "Like many who borrow concepts from other fields, organizational writers have oversimplified matters to such an extent that their concept has lost much of its connection to the usages that are current in the field to which it belongs."

Apostolakis and Wu [11] questioned whether the term safety culture is appropriate by suggesting it is too narrowly drawn. "When the subject is culture, we must question the wisdom of separating safety culture from the culture that exists with respect to normal plant operation and power production. The dependencies between them are much stronger because they are due to common work processes and organizational factors." Reason [12] also notes that the quality of production and protection depend on the same organizational processes.

Despite the reservations of some investigators, safety culture seems to be accepted as an appropriate and useful concept, even though its relationship to 'culture' in the usual sense is tenuous. Ascribing the usually understood characteristics of 'culture' to 'safety culture' should be done with some caution. The term itself implies that it is a subset of a larger 'organizational culture.'

Safety culture may not capture all the management and organizational factors that are important to safe plant operation, but it has acquired a place in the literature. Although the literature does not support any single definition of safety culture, it is probably reasonable to settle on a model that represents organizational culture as a particular application of the larger concept of culture, and then considers safety culture as a subset of organizational culture. The definition chosen for 'safety culture' should then be consistent with its parent terms, 'culture' and 'organizational culture.' The ultimate objective is to establish a link between safety culture and safety of operations. That process requires not only a definition, but also a delineation of the characteristics or attributes of safety culture. Such attributes should be consistent with the chosen definition, but they are probably more important than the definition.

4. Safety culture in context

Safety culture, however defined, is part of the larger issue of human factors. In a 1988 study requested by the NRC, the National Research Council recommended a human factors research agenda to be undertaken by the NRC [13]. The recommended program included five major areas: human–system interface design, the personnel subsystem, human performance, management and organization, and the regulatory environment. The first two areas are primarily related to system design and personnel training, respectively, and are only indirectly related to safety culture. The next two areas, human performance and management and organization, are most closely related to the idea of safety culture. Under human performance, the National Research Council identifies the highest priority topic as causal models of human error. Under management and organization, it identifies two high priority topics: the impact of regulations on the practice of management, and organizational design and a culture of reliability. Equating 'culture of reliability' to what we are now calling 'safety culture' seems like a reasonable step.

Safety culture is also related to the last area mentioned by the National Research Council, regulatory environment, but not in a simple way. Regulatory activities influence the overall environment in which licensee organizations operate, and hence affect the organizational cultures that evolve. Regulatory activities also have the potential for being counterproductive, especially if they appear to shift the responsibility for safety from the operator to the regulator.

4.1. Human error

The focal point of human factors concerns is the performance of individuals. The term 'human error' is generally understood to mean an unsafe act by a system operator. The consequences of such an act may or may not be severe, depending on other circumstances. Such 'other circumstances' are often the product of organizational factors that established other important conditions that determine system response. In his taxonomy of human error, Reason [14] distinguishes between active errors, "whose effects are felt almost immediately," and latent errors, "whose adverse consequences may lie dormant within the system for a long time." Active errors are usually associated with system operators such as airplane pilots, air traffic controllers, or power plant control room personnel. Latent errors are normally associated with personnel removed from operations, such as design, construction and maintenance personnel.

Modeling human error is necessary to the complete understanding of the human contribution to system safety. Information from human error models and associated data gathering are an important input to the process of PRA. The probability of an operator committing an error and causing a system to fail to perform its intended function is as important as a component failure leading to the same result. Modeling unsafe acts, however, is only part of the story. The consequences of those acts often depend on latent errors. It seems reasonable to expect that safety culture, and probably other organizational factors, will have a significant influence on both the frequency of unsafe acts and the probability of latent errors.

4.2. Organizational accidents

In *Human Error*, Reason argues that most of the root causes of serious accidents are present within the system long before an obvious accident sequence can be identified. He contends that "... some of these latent failures could have been spotted and corrected by those managing, maintaining and operating the system in question." In a second book [12], he looks at the organizational functions involved in creating or mitigating accidents. He argues that "...human error is a consequence, not a cause. Errors ... are shaped and provoked by upstream workplace and organizational factors [12, p. 126]." He calls the accidents resulting from such upstream factors 'organizational accidents.' Understanding the management and organizational factors that can either reduce or identify and correct latent errors is an important element in reducing the frequency and consequences of accidents.

Typically, organizational accidents involve "...the interaction of latent conditions with local triggering events [12, p. 35]." Reason describes organizational accidents in terms of organizational factors, local workplace factors and unsafe acts. The organizational factors and local workplace factors not only interact directly, but each may create latent condition pathways. Accidents with significant losses occur when all these conditions align in such a way that the defenses built into a system are overwhelmed. Reason maintains that latent conditions may be sufficient to cause accidents, and that they are always present in the system.

The NRC has developed a human reliability analysis method called ATHEANA (A Technique for Human Event Analysis) [15]. The issues addressed by the concept of safety culture in general, and latent errors in particular, provide what is called the 'error forcing context' for ATHEANA. The model provides a structured search process for human failure events, including detailed search processes for error-forcing context, and an improved representation of human–system interactions.

The ATHEANA process contributes to the objective of systematically identifying important management and organization factors that contribute to significant event sequences. The ATHEANA analysis of the Wolf Creek drain-down event [16] identified a number of management and organization factors that contributed to the occurrence of the event. Contributors included incompatible work activities, a compressed outage schedule, poor mental models of the systems and valves, heavy reliance on the control room crew to identify problems, and inadequate reviews of procedures prior to use.

The influence of latent errors was identified in a recent study by the Idaho National Engineering and Environmental Laboratory (INEEL) [17]. One objective of the study was to identify the influence of human performance in significant operating events. INEEL analyzed 35 operating events, 20 of them using PRA methods. Event importance, as measured by conditional core damage probability, ranged from 1.0×10^{-6} to 5.2×10^{-3}.

INEEL found that most identified errors were latent, with no immediate observable impact. The ratio of latent to active errors was 4:1. Latent errors identified included design deficiencies, failure to correct known problems, incomplete design change testing, inadequate maintenance practices and post-maintenance testing, and poor work package quality assurance. The INEEL discussion does not seem to distinguish between the latent error itself, such as a design deficiency, and the root cause of the latent error, such as inadequate design review or incomplete design change testing. Active errors included failures in command and control (such as loss of phone communications), and incorrect operator actions (such as incorrect system line-ups or acting without procedural guidance).

The INEEL findings are supported by other analyses. In discussing a human performance improvement program at Duke Power Company, one Duke Power senior manager observed that "If you analyze an entire event,... you'll find it wasn't just one mistake—it was five, six or seven mistakes that occurred and there weren't enough contingencies or barriers built in to prevent the event from happening [18]."

A structured assessment by Duke Power of human performance needs identified the need for focused human error reduction training for technicians and supervisors. Although the term 'safety culture' is not used in describing the program, it incorporates elements and issues practically identical to many of those addressed by INSAG-4. One element in the Duke Power program, for example, is 'individual commitment' which includes a questioning attitude, procedure use and adherence, communications, stopping when unsure, and an overall prudent approach. The same parallels exist for the manager's commitment portion of the INSAG model and the supervisors and manager's sections of the Duke Power program. Both deal with clear priorities, goals and responsibilities, clear lines of responsibility and authority, staff skills and competence and performance assessment.

Since the program was initiated, refueling outage times at Duke Power's McGuire nuclear power station have been reduced from about 90 days to about 33 days, and capacity factors have increased from about 72% to about 89%. These results, of course, are measures of efficiency, not safety. The similarity between the management and organization factors apparently responsible for the noted improvements and those factors identified with safety culture suggests that an attempt to relate safe operations to efficient operations might be worthwhile. It is often claimed that efficient, well-managed facilities from a production standpoint are also safe facilities. That notion is not universally accepted, and probably requires a more rigorous examination than it has been given to date. Such an examination may be valuable.

5. Relating safety culture to safety performance

As noted previously, one of the omissions in INSAG's structure for establishing and evaluating safety culture is the link between safety culture and safety of operations. The INSAG approach assumes, but does not attempt to demonstrate, a positive relationship between safety culture and facility safety. There are actually two parts to this demonstration. The first part is to establish a relationship between safety culture (or its associated attributes) and safety of operations. The second part is to determine if there are suitable performance indicators that can be used to infer changes in safety culture and, thereby, predict changes in safety performance. There is a substantial body of literature that addresses the first part of the problem. There is much less work that addresses the second part. No performance indicators to gauge safety culture and its impact on safety of operations appear to have been identified and validated.

An activity diagram for establishing a relationship between safety culture and safety, the first part of the problem posed above, is shown in Fig. 1. The objective is to identify one or more measurable attributes of safety

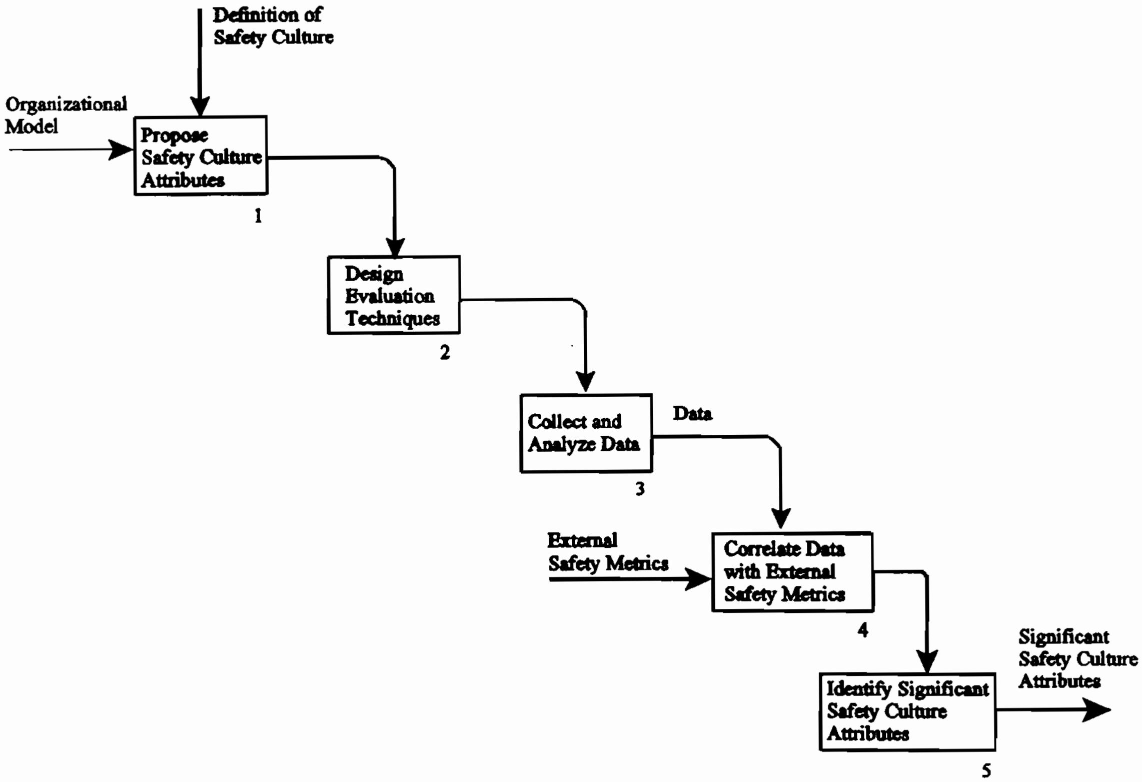

Fig. 1. Relating safety culture to safety performance.

culture that can be correlated with one or more measures of operational safety. The second part of the problem, identifying suitable performance indicators, is outlined in Fig. 2.

Research intended to show how management and organization factors affect safety of operations typically starts with a description of how a particular organization works, and attempts to identify specific, measurable organizational factors that influence safety. The process necessarily requires some measure of safety, such as the frequency of accidents. The analyst may begin by choosing an organizational model to represent how the organization works. The insights derived from that model, in conjunction with a suitable definition of safety culture, can be used to suggest attributes of safety culture that can be measured (step 1 in Fig. 1). Such attributes might include, for example, effectiveness of organizational communications, organizational learning, management attention to safety, and management expectations regarding compliance with procedures.

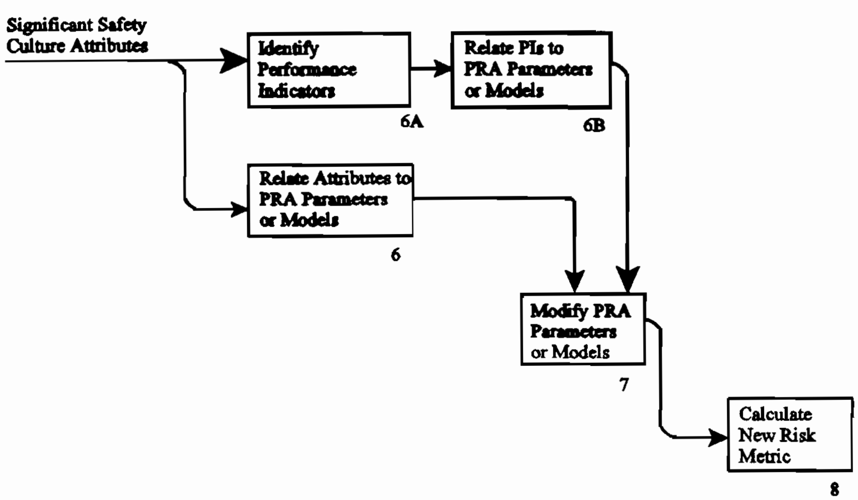

Fig. 2. Relating safety culture to risk metrics.

The next step in the process is to design methods to measure the proposed attributes in a real organization. This is typically done using audits, inspections, document reviews and personnel surveys. The tools and techniques used here often include those used by psychologists as well as those used by engineers. To continue the example, designing the measurement methods would involve finding a way to quantify 'management attention to safety' and the other proposed attributes of safety culture. Selection of the measurement techniques is obviously followed by data collection and analysis (step 3 in Fig. 1).

The next step is to correlate the attribute measurements with one or more measures of operational safety. This step obviously requires the analyst to select external safety metrics. The choices may be dictated by what measures are available. Early studies of US nuclear power plants used systematic assessment of licensee performance (SALP) evaluations, licensee event reports (LERs), and other performance indicators such as unplanned scrams, safety system actuations, and safety system failures.

Correlation of the safety culture attribute data with the chosen safety metrics (step 4) is usually done using regression analysis. The result typically will show that some of the proposed attributes have a statistically significant relationship with one or more of the chosen safety indicators. An organization with a low score on 'management attention to safety,' for example, might consistently have a relatively high rate of safety system failures. Other attributes may show no significant correlation. The output of the process at this point (step 5 in Fig. 1) is the identification of those attributes of safety culture that show a significant relationship to safety, at least as measured by the chosen safety metrics.

Addressing the second part of the problem, identification of suitable performance indicators and the impact of safety culture attributes on risk metrics, is outlined in Fig. 2. As shown in the lower path on Fig. 2, the significant safety culture attributes must be related to parameters in a PRA, such as a human error probability, a system failure probability, or a system unavailability. Essentially, a numerical value must be developed for each of the significant elements. An algorithm is then developed to relate the resulting quantification to a change in one or more PRA parameters, such as a system unavailability or failure rate. To pursue the example of the attribute 'management attention to safety,' the desired algorithm could relate a low score on this attribute to an increase in assumed equipment failure rates used as input to the PRA. It is also possible that a relationship identified between the significant attributes and the external safety metrics is not modeled in the PRA at all. In this case, the PRA model itself must be modified. The final step on this path is the calculation of core damage frequency or other chosen risk metric.

If the overall process described above is to be most useful in the safety assessment of hazardous facilities, it is desirable to identify easily obtainable performance indicators that will provide a reliable measure of the significant safety culture attributes. This possibility is illustrated in the upper path of Fig. 2. Evaluating the attribute 'management attention to safety,' for example, might require extensive data collection and data analysis. Once the relationship between 'management attention to safety' and safety system failure rates has been established, it may be possible to identify an easily observable surrogate for 'management attention to safety.' Such a performance indicator might be the fraction of employees participating in periodic safety training. This indicator could be monitored through record reviews, and would not require the personnel surveys and audits that might otherwise be necessary to measure 'management attention to safety.' If suitable performance indicators for the attributes of safety culture can in fact be identified, the performance indicators can also be related, in turn, to the PRA parameters or PRA models.

6. Modeling organizations

This section reviews some of the literature that addresses studies related to establishing a relationship between safety culture (or other management and organizational factors) and safety of operations. The models discussed in each of the studies reviewed address some of the activities represented in Figs. 1 and 2. None of them treat all activities, at least not with the same degree of thoroughness and rigor. Typically, a given study will address a few activities in detail, and acknowledge the need to address the remainder. Some studies consider safety culture to be a subset of the management and organizational factors that might affect safety, and others do not use the term 'safety culture' at all. The studies selected for review are a representative but limited sample of the available literature, not an exhaustive survey.

6.1. Chemical industry safety surveys and audits

Investigators in the chemical process industry have used safety audits and personnel surveys as the primary means of relating safety attitude or safety culture to operational safety. Investigators in this field have the advantage, if it can be deemed an advantage, that certain types of accidents occur with sufficient frequency to provide statistically valid measures of operational safety.

Donald and Canter [19] examined the relationship between employee attitudes and safety performance in the chemical process industry using the terms 'safety attitudes' and 'safety climate' instead of 'safety culture.' The authors use the term 'organizational climate' as the sum of perceptions employees have of their organizations. The climate represents the context in which behavior occurs and the basis of people's expectations.

Donald and Canter began their study by deriving six factors associated with safety from the relevant literature:

- management commitment
- safety training
- open communication
- environmental control and management
- stable workforce
- positive safety promotion policy

Other factors were found, using expert judgment, that discriminated between factories (locations) in terms of safety climate. In order of decreasing discriminant power they were:

- importance of safety training
- effects of workpace (sic)
- status of safety committee
- status of safety officer
- effect of safe conduct on promotion
- level of risk at the workplace
- management attitudes toward safety
- effect of safe conduct on social status

These factors are summarized in the first column of Table 1.

The evaluation technique used by Donald and Canter was an employee survey based on three facets of safety attitude: people, attitude behavior, and activity. The 'people' facet was divided into five components: self, workmates, supervisors, managers, and safety representatives. Attitude behavior was divided into three components. The first was an employee 'knowing about' something related to safety, the second was an employee being 'satisfied with' something about safety, and the third was an employee 'carrying out' some action related to safety. The 'activity' facet addresses the degree to which an employee engages in activities important to safety. The elements of each of the facets were used to construct ten 'scales' to measure worker attitudes toward safety and their perception of other peoples attitudes. The ten scales are summarized in the second column of Table 1.

Table 1
Attributes related to safety in the chemical industry from Donald and Canter [19]

Attributes derived from the literature	Proposed attributes to be tested empirically
	People facet
Management commitment	Self
Safety training	Workmate
Open communications	Manager
Environmental control and management	Supervisor
Stable workforce	Safety representatives*
Positive safety promotion policy	
Attributes found using expert judgment	*Attitude behavior facet*
Importance of safety training	Satisfaction
Effects of workpace (*sic*)	Knowledge
Status of safety committee	Action
Status of safety officer	
Effect of safe conduct on promotion	*Activity facet*
Level of risk at the workplace	Active
Management attitudes towards safety	Passive
Effect of safe conduct on social status	

* Attribute marked with an asterisk did *not* correlate with low self-reported accident rates.

Question templates were designed to map all three facets into specific questions related to safety climate. One such template, for example, would be the combination of "workmate (people facet) is satisfied with (attitude facet) passive safety activity (activity facet)." An example of a question developed from that template is "To what extent are your workmates satisfied with the safety procedures they are required to follow?"

Each of the ten scales was represented by a set of questions based on the templates described earlier. In addition, each participant in the survey was asked about their involvement in accidents. These 'self-reported accident rates' were the safety metric chosen for the study. The survey was conducted at ten plants owned by the same company. The results indicated that the attitude scales were a reliable measure of safety climate. Only one scale, safety representatives, did not show a statistically significant correlation with self-reported accident rates. Overall, there was a "...clear and strong relationship between the safety attitude climate of a company and its accident performance."

Note that the work just described did not extend to the activities displayed in Fig. 2. There was no attempt at identification of performance indicators as surrogates for either the accident rates or the attributes of safety climate, nor was there any attempt to quantify the level of risk represented by particular values of the safety climate scales.

6.2. Safety survey of a nuclear fuel reprocessing plant

Lee [3] reported on an assessment of safety culture at the Sellafield nuclear reprocessing plant, which can perhaps be considered as belonging both to the nuclear industry and the chemical process industry. Lee noted that the concept of safety culture is not new, and had existed for some years as 'safety climate,' which in turn was one aspect of a broader 'organizational climate.'

Lee's description of the traditional approach to safety reflects the process that has been used within the US regulatory system. "The traditional approach to safety... has been retrospective, built on precedents. Because it is necessary, it is easy to think it is sufficient. It involves, first, a search for the primary (or 'root') cause of a specific accident, a decision on whether the cause was an unsafe act or an unsafe condition, and finally the supposed prevention of a recurrence by devising a regulation if an unsafe act, or a technical solution if an unsafe condition." Although maintaining that this process is necessary, Lee went on to note that it has serious shortcomings. Specifically, "Regulations are proliferated to the point where they become incomprehensible and... resources are diverted to prevent the accident that has happened rather than the one most likely to happen."

Lee started with a list of characteristics of low accident plants distilled from a review of empirical research into the organizational aspects of safety. The list included a high level of communications, good organizational learning, a strong focus on safety, strong commitment to safety by senior management, a management leadership style that is democratic, cooperative, participative and humane, more and better quality training, good working conditions, high job satisfaction and a workforce retained for safe working habits.

These characteristics, summarized in the first column of Table 2, are similar to those used as a starting point by Donald and Canter (the first column of Table 1). Lee then identified 19 attitudes toward safety (safety culture attributes) to be tested empirically. Lee's attributes are listed in the second column of Table 2, and bear some similarity to those examined by Donald and Canter. The evaluation process involved both focus groups and an employee questionnaire consisting of 172 statements about safety. Respondents could indicate a range of agreement/disagreement on a seven-point scale. The safety metric chosen was self-reported rates of accidents involving three or more days of lost work.

Lee's results showed a strong correlation between positive safety attitudes and low accident rates. Of the 19 factors, 16 showed a statistically significant correlation, 15 of those at a very high level of significance.

Lee concluded that, "The concept of safety culture... now has widespread support. If it is a valid concept... [it] should be helpful in getting employees to understand the objectives of a safety management system... However, the sheer multiplicity of constituent elements of a safety culture and its precept of universal involvement imply that any attempt to monitor its health... is bound to be complex...."

6.3. An organizational analysis approach

Work begun for the NRC at Pacific Northwest Laboratory (PNL) in the early 1980s focused primarily on the relationship between the structure of the utility organization and safety performance. The first of these reports [20] addressed identifying appropriate organizational factors (step 1 of Fig. 1) and possible external safety metrics (the input to step 4).

Drawing on work done in organizational analysis, Osborn et al. [20], proposed a model based on categories of variables they called 'organizational contingencies' and 'intermediate outcomes.' Under the heading of organizational contingencies, potential important organizational factors were grouped into four types: environment, context, governance, and design. The utility environment includes general economic trends, regulation by the state, regulation by the NRC, support from vendor organizations, and interfaces with corporate parents. The second factor, the utility's context, includes its history, size and technology. The third factor, organizational governance or management philosophy, is characterized by three types: (1) traditional, which emphasizes a bureaucratic approach including administrative control, written policies, and elaborate written procedures; (2) modern, which emphasizes values where individual judgment is to be used to implement policy; and (3) federal, which stresses negotiation and

Table 2
Organization factors related to safety from Lee [3]

Characteristics of low accident plants	Proposed safety attitudes (safety culture attributes) to be tested empirically
High level of communication	Confidence in safety procedures
Good organizational learning	Personal caution over risks
Strong focus on safety	Perceived level of risk at work
Strong senior management commitment to safety	Trust in workforce
Democratic, cooperative, humanistic management leadership style	Confidence in efficiency of 'permit to work' system*
More and better quality training	General support for 'permit to work' system
Clean, comfortable working conditions	Perceived need for 'permit to work' system*
High job satisfaction	Personal interest in job
Workforce retention is related to working safely	Contentment with job
	Satisfaction with work relationships
	Satisfaction with rewards for good work
	Personal understanding of safety rules
	Perceived clarity of safety rules*
	Satisfaction with training
	Satisfaction with staff suitability
	Perceived source of safety suggestions
	Perceived source of safety actions
	Perceived personal control over safety
	Satisfaction with design of plant

* Attributes marked with an asterisk did *not* correlate with low accident rates.

Table 3
Management and organizational factors related to safety performance

Organizational analysis approach Marcus et al. [22]	Organizational process approach Jacobs and Haber [25]
Environmental conditions	*Administrative knowledge*
General environment	Coordination of work
Abundance of resources	Formalization
Amount of volatility	Organizational knowledge
Amount of interdependence	Roles and responsibilities
Task environment	
Abundance of resources	*Communications*
Amount of volatility	External
Amount of interdependence	Interdepartmental
	Intradepartmental
Contextual conditions	
Size (staff and budget)	*Culture*
Technological sophistication	Organizational culture
Technological variability	Ownership
	Safety culture
	Time urgency
Organizational governance	
Traditional, modern or federal	*Decision making*
	Centralization
	Goal prioritization
Organizational design	Organizational learning
Mechanistic, organic or diverse	Problem identification
	Resource allocation
Intermediate outcomes	*Human resource allocation*
Efficiency	Performance evaluation
Compliance	Personnel selection
Quality	Technical knowledge
Innovation	Training

integration of differing views through conflict resolution. The fourth factor, organizational design, includes how work is divided among units; the nature of controls placed on individuals, managers and operational units; coordination mechanisms; and developmental mechanisms, which reinforce and direct decisions by individuals.

The second category of variables, called 'intermediate outcomes,' includes four factors: compliance, efficiency, quality and innovation. These factors appear to be included in the model to account for organizational characteristics closely related to safety and to external regulation. These organizational factors, the output of step 1 in Fig. 1, are summarized in the first column of Table 3.

The safety metrics chosen for the PNL work were typical of the early attempts to identify such indicators. Included in the preliminary list are LERs, inspection and enforcement data, operating and outage data, SALP scores, personnel exposure, and operator exam scores.

A second report [21], published about a year after the preliminary work, claimed some success with the proposed approach, although the results were still labeled as preliminary. Specifically, the report concluded that plant performance data could be used to create reliable indicators of plant safety performance, that plant safety performance indicators are potentially useful for identifying causes of poor performance, and that organizational structure appears to be an important predictor of plant safety performance.

The approach described above is focused on the structure of the organization. It is based on a body of work in organizational analysis that appears to have virtually no overlap with the proponents of corporate culture. The organizational factors considered are not components of organizational culture or safety culture, and have different properties. It is interesting to note, however, that the later work by these investigators acknowledges the possible importance of the concept of organizational culture. Specifically, work done following the Bhopal, Challenger and Chernobyl accidents prompted the authors to note, "Collectively, these analyses suggest that relationships that emerge from the day-to-day operation of technologies are potentially as important as the more general state conditions and management philosophy concerns described earlier. [T]hese management relationships... are those unplanned continuing dynamics of the organization that allow it to operate with continuity and react to unanticipated conditions. They arise because individuals shape and mold the formal organization, interpret the environment and context, implement the management philosophy and generally add variety to that planned into the system [22, p. 51]."

6.4. An organizational process approach

The approach proposed and developed by Haber et al. [23], is based on organizational processes as opposed to organizational structure. As with the organizational structure approach pursued at PNL, the underlying idea is to seek statistically valid relationships between organizational factors and safe plant operations. The three-step process used was (1) development of a description of the human organization of a nuclear power plant, (2) identification of organizational and management functions and processes related to safety performance, and (3) the development of methods for measuring organizational and management factors. The overall concept was designated Nuclear Organization and Management Analysis Concept.

The assessment of organization and management factors involved three types of data collection: a functional analysis, a behavioral observation technique and an organizational culture assessment. The functional analysis provides a description of the work flow, behavioral observation identifies patterns of communication, and the culture assessment describes the environment of the organization. Two demonstration studies, one at a fossil power plant and one at a nuclear power plant, identified five organizational factors for further investigation: (1) communication, (2) organizational culture, (3) decision-making, (4) standardization of work processes, and (5) management attention, involvement and oversight.

Organizational culture in this work was described as "...

the beliefs, perceptions, and expectations that individuals have about the organization in which they work and about the values and consequences that will follow from one course of action or another. Consequently, culture highly influences behavior within the organization." 'Safety culture' is considered to be an element of organizational culture. Organizational culture in the demonstration studies was measured using employee questionnaires.

Jacobs et al. [24], adopted a similar viewpoint based on organizational processes. The paper identifies five organizational factors as relevant to safe operations: culture, administrative knowledge, communications, decision-making, and human resource allocation. This is similar, but not identical, to the list developed by Haber et al. In addition to identifying the five factors, Jacobs assigns several dimensions to each as shown in the second column of Table 3. A somewhat later joint paper by Jacobs and Haber [25] uses Jacob's list of organizational factors and dimensions.

Table 3 lists the organizational factors chosen for investigation in the organizational analysis approach described earlier [22], and those proposed by Jacobs and Haber. A comparison of the two columns shows the emphasis on structure and conditions in the first column and the emphasis on process in the second column. Both approaches are designed to relate management and organizational factors to safety performance. The organizational analysis approach was designed to rely as much as possible on publically available records. The organizational process approach, on the other hand, depends heavily on inferring organizational characteristics from surveys and interviews of a broad spectrum of personnel in the organization. It attempts to determine how an organization works, as opposed to how it is structured.

6.5. Work process analysis

Davoudian et al. [26] have proposed an approach to modeling the organization that uses elements of both organizational structure and organizational process. The ultimate goal is to develop a methodology for incorporating organizational factors into PRAs. This work has evolved over the last few years [11,27]. The analysis begins with asking the question "how is the organization supposed to work?" and then addressing "how well is it working?" The categories and dimensions of important organizational factors as articulated by Jacobs and Haber [25] are adopted. An examination of work processes is then proposed as a way to analyze and possibly quantify the importance of those factors.

The work process analysis methodology starts with the observation that the structure of an organization is determined by two basic elements: division of labor and coordination of effort. Division of labor is accomplished by creating work units, typically based on functional specialization. Examples are operations, maintenance, instrumentation and control, and health physics. Coordination is accomplished by both formal and informal mechanisms, including policies, procedures, scheduled meetings and unscheduled meetings. Work processes within a functional unit tend to be standardized and controlled by written procedures. The objective of the work process analysis methodology is to identify the organizational factors that can impact the performance of particular tasks, and ultimately to quantify those impacts as changes in PRA parameters (failure rates, human error probabilities or system unavailabilities).

The first step in the work process analysis model (WPAM) is the identification of front-line and supporting work processes. Front-line process are those that have a direct influence on the operability of plant hardware, such as plant operation, maintenance, and modifications. Supporting work processes include training, procurement and quality control. For each work process, the following basic question is posed: how can an accumulation of organization failures lead to an unsafe plant condition?

Each task in a given work process can be influenced by several organizational factors. In fact, one of the strengths suggested for this approach is its ability to identify organizational deficiencies that could disable dissimilar components. If the analysis is to be extended to quantification of the impacts on human error rates or system unavailability, it is necessary to rank the organizational factors according to their degree of influence on each task. One method of performing the ranking is the analytical hierarchy process. This involves assigning relative weights to each pair of pertinent factors (pairwise comparison). Presumably other ranking methods could be used.

In a 1999 paper [28], Weil and Apostolakis propose that the 20 organizational factors identified by Jacobs and Haber [25] can be reduced to six without impairing the effectiveness of the work process analysis methodology. The six factors retained are: communications, formalization, goal prioritization, problem identification, roles and responsibilities, and technical knowledge. These six were chosen by identifying factors that affected a large number of tasks and/or were often cited as contributing to errors, and by excluding factors that logically could be combined into one of the remaining factors.

6.6. A model based on expert elicitation

The Swedish Nuclear Power Inspectorate (SKi) has sponsored a study to develop a risk based performance monitoring system for nuclear power plants using expert elicitation to identify organizational and operational-based safety related performance indicators [29]. The model is based on a probabilistic safety assessment of the plant. Starting with a proposed list of 78 performance indicators, a final list of five high worth indicators is derived. The five indicators are:

- annual rate of safety significant errors,

- annual rate of maintenance problems,
- ratio of corrective to preventive maintenance on safety equipment,
- annual rate of problems with repeated root cause, and
- annual rate of plant changes that are not incorporated into design-basis documents prior to the next outage.

These indicators are proposed as a suitable measure of safety culture. Ultimately, the assessment of safety culture (superior, above average, average, below average, or inferior) can be used to modify equipment failure rates or system unavailabilities.

The SKi process is particularly interesting because it replaces virtually all of the activities represented in Fig. 1 with expert elicitation. Step 1 is represented by the initially proposed list of 78 performance indicators. Steps 2–5, are replaced by the expert elicitation process, with the output being the final list of five high worth indicators. Since the methodology includes an algorithm for quantifying the impact of the performance indicators on risk metrics, it provides a means of addressing the upper path of Fig. 2.

6.7. A summary of the empirical evidence

There is a substantial body of literature dealing with the relationship between safety culture and safety of operations. That literature is fragmented, however, and it is often difficult to understand how one piece of work relates to another, if at all. The scope, depth, terminology and perspective vary widely from one study to the next.

The first source of difficulty is terminology. There is general agreement on the concept of safety culture, and some agreement on its attributes. Many of the studies relating management and organization factors to safety of operations do not use the term 'safety culture.' If it is used, it may denote a narrowly defined element of a larger set of management and organization factors being investigated. One study can only be compared with another by looking at the organizational attributes that are actually measured. The study of safety culture might benefit substantially if a consensus could be developed on its definition, and, most importantly, its measurable attributes.

A second source of difficulty is the availability of suitable safety metrics. The chemical processing and transportation industries have sufficiently high occurrences of unwanted events that it is possible to correlate management and organization factors with accident rates. Other activities, including nuclear power generation, have sufficiently low accident rates that the accident rates provide no basis for comparing one facility to another. Instead, investigators select performance indicators, such as the number of unplanned scrams, as surrogates for safety performance.

Olson et al. [30] illustrate the issue by distinguishing among three categories of information: (1) plant performance indicators, (2) penultimate measures of safety, and (3) ultimate measures of plant safety. They suggest that the ultimate measures of plant safety are the unwanted events: core melt, large releases of radionuclides, and large population exposures. The penultimate measures of safety are potentially significant events, releases of radionuclides, and personnel exposures. (Analyses of potentially significant events to determine conditional core damage probability or conditional large early release frequency can partially bridge the gap between the penultimate and ultimate measures of safety.) Plant performance indicators might include the number of LERs, operating and outage data, and the number of violations of NRC regulations. The use of performance indicators as a measure of safety should include establishing a relationship between the indicator and the likelihood of an unwanted event. Current NRC work to identify risk based performance indicators is intended to address this issue [31].

No studies relating safety culture and safety of operations were identified which addressed all of the activities outlined in Figs. 1 and 2. Studies of the chemical process industry addressed all of the activities in Fig. 1, and provided empirical evidence that safety attitudes have a positive relationship to safety of operations. Those studies did not address identifying performance indicators (Fig. 2).

Studies of nuclear power plants focused on identifying management and organization factors important to safety of operations, but they lack the extensive field data collected in the chemical process industry studies. The work started at PNL by Osborn et al. [20], involved extensive empirical analyses relating organization factors to performance indicators, but did not examine attributes of safety culture. The work begun at Brookhaven National Laboratory by Haber et al. [23], did address organizational factors related to safety culture, but data collection and analysis concentrated on measuring those attributes and validating the measurements. Data collection appears to have been limited to one fossil and two nuclear power plants, and very little was reported on establishing an empirical relationship between the organizational factors and indicators of safety performance.

Overall, substantial work has been done to validate the idea that safety culture and other management and organization factors have a strong relationship to safety of operations. Most of the empirical work has been done outside the nuclear industry. Some investigators believe that results cannot be extrapolated from one industry to another without justification that does not now exist [32]. It appears that Lee [3] has characterized the situation correctly: "There has been little direct research on the organizational factors that make for a good safety culture. However, there is an extensive literature if we make the *indirect* assumption that a relatively low accident plant must have a relatively good safety culture" (emphasis in original). The proponents of safety culture as a determinant of operational safety in the nuclear power industry are relying, at least to some degree, on that indirect assumption.

7. Regulatory perspectives

Regulatory organizations have an interest in safety culture because it is now widely believed that there is a relationship between safety culture and safety of operations. The most obvious link suggested by work done to date is that a good safety culture is expected to reduce human error rates. Reason [12] suggests that well-defended technologies, those that use several layers of defense in depth such as nuclear power plants, may be especially vulnerable to an unsafe culture. He points out that the effect of a poor safety culture is to create gaps or holes in the defenses, which are not readily apparent (latent errors), thus making the system vulnerable to a serious accident when the right initiating event occurs. Defenses in depth make the system more opaque to the operators, and the operators are more remote from the processes they are controlling. An important question remains as to whether safety culture should be addressed by the regulatory process. That question probably cannot be answered without considering *how* it might be addressed by the regulatory process.

INSAG [5] asserts that safety culture is attitudinal as well as structural, and that it relates to both organizations and individuals. Lee [3] suggests that the safety improvements to be achieved through engineering are limited, and that additional improvements require addressing the "hearts and minds of the management and workers." Studies sponsored by the NRC [33,34] have shown a positive correlation between management and organizational factors and selected safety indicators. Studies outside of the nuclear industry [19,35] have shown strong positive correlations between organizational characteristics associated with safety culture and low accident rates.

Although there is no universally accepted definition, there is some common ground among investigators on the elements of safety culture. Most investigators appear to agree that the elements include good communications, organizational learning, senior management commitment to safety, and a working environment that rewards identifying safety issues. Some investigators would also include management and organizational factors such as a participative management leadership style. The regulatory dilemma is that the elements important to safety culture are difficult, if not impossible, to separate from the management of the organization.

Historically, the NRC has been reluctant to regulate management functions in any direct way. Licensees have been even more reluctant to permit any moves in that direction. The argument is, of course, that licensees are responsible for the safe operation of their facilities, and they must be permitted to achieve safety in their own operating environment in the best ways they know. The closest NRC has come to evaluating management performance is the SALP program, which the agency has discontinued. Throughout its life it was criticized by licensees as lacking objectivity.

7.1. Safety culture as a basis for safety regulation

One of the most comprehensive reviews of the relationship between safety culture and safety of operations was undertaken for the United Kingdom Health and Safety Executive by its Advisory Committee for the Safety of Nuclear Installations (ACSNI) [36].

ACSNI concludes, from USNRC sponsored work, that the key predictive indicators of safety performance are effective communication, good organizational learning, organizational focus on safety, and external factors such as the financial health of the organization and the impact of regulatory bodies. It holds that, "The best safety standards can arguably only be achieved by a programme which has a scope well beyond the traditional pattern of safety management functions." It characterizes the evolution of safety regulation as follows:

> "There are three phases in the history of attempts to regulate general industrial safety.
> First, there is a stage of concentration on the outcome; if a worker or a member of the public is harmed, those considered responsible are punished.
> Second, there is a stage of prescribing in advance the detailed action that industry must take. For example the organisation must provide guards of certain types for specific machines.... This stage is an advance because it attacks points of danger before actual harm occurs....
> In the third stage, industry is canvassed to develop a 'safety culture'... This stage of regulation... concentrates on the internal climate and organization of the system [and] also emphasizes the need for every individual to 'own' the actions being taken to improve safety...."

In examining the regulator's role in influencing licensee organizational behavior, the ACSNI human factors study group maintained that, "The behavior of the regulators will affect the culture of the licensees.... The regulators need to act in such a way as to encourage 'ownership' of safety by the whole staff of the licensee [36, p. 47]."

A theme that runs through the ACSNI study is that the most effective safety cultures will develop in less prescriptive regulatory structures. "The most impressive achievements appear in companies where the pressure for safety has been generated from within the organization, apparently independent of external standards [36, p.16]."

A subsequent report [37] notes that "It is recognized that there are a number of prescriptive regimes, such as the U.S. Nuclear Industry, where the encouragement of a positive safety culture is still essential. It is considered that those Operators with good Safety Cultures, within the US regulatory regime, tend to self-regulate around the constraints of the regulatory regime, to attain levels of safety which are beyond those minima specified in the regulations. The manner in which the Regulator can encourage such self-regulation is not clear [37, p. 34]."

One aspect of this idea is explored in some detail in an earlier paper by Marcus [38], in which he examines the implementation of certain NRC requirements at several U.S. nuclear power plants. His conclusion was that, "...nuclear power plants with relatively poor safety records tended to respond in a rule-bound manner that perpetuated their poor safety performance and that nuclear power plants whose safety records were relatively strong tended to retain their autonomy, a response that reinforced their strong safety performance."

7.2. International activities

The IAEA has continued to develop the concept of safety culture as an important contributor to safety of operations, and therefore as an important issue to be addressed by the regulatory process. A 1998 publication is devoted to offering "...practical advice to assist in the development, improvement or evaluation of a progressive safety culture [39]." A revision to INSAG-3 was issued in 1999 to provide, among other things, "A more comprehensive treatment of safety culture and defense in depth [40]." INSAG-13 [41] was also issued in 1999 to "...build upon the ideas outlined in 75-INSAG-4 [Safety Culture] and to develop a set of universal features for an effective safety management system in order to develop a common understanding."

The Nuclear Energy Agency (NEA) has also become engaged in promoting safety culture as an important part of safety regulation. A 1999 publication, "The Role of the Nuclear Regulator in Promoting and Evaluating Safety Culture [42]," suggests signs that a regulator should look for to determine the strength of a licensee's safety culture. It also provides suggestions for regulatory response to a weakening safety culture, although the suggestions are very general. A subsequent report deals more specifically with the issue of regulatory response [43].

NEA has also issued a 'state-of-the-art' report [44] on the identification and assessment of organizational factors related to nuclear power plant safety. Volume 1 lists and discusses 12 organizational factors:

- external influences,
- goals and strategies,
- management functions and overview,
- resource allocation,
- human resources management,
- training,
- co-ordination of work,
- organizational knowledge,
- proceduralization,
- organizational culture,
- organizational learning,
- communication.

This list is similar, but not identical, to the list of attributes proposed by Jacobs and Haber (Table 3, second column).

The second volume of the report summarizes the regulatory framework used in nine OECD countries, including France, the United Kingdom and the United States. In each case the discussion addresses how the regulatory process considers management and organization factors. Most of the regulatory programs discussed include some evaluation of management and organization factors. By contrast, the NRC program does not involve direct evaluation of management performance.

Volume 2 of the NEA report [44] also provides summaries of research programs on management and organization factors. The programs described are directed at identifying management and organizational factors important to safety of operations, incorporating management and organization factors into PRAs, or evaluating the attributes of safety culture within a licensee's organization.

7.3. Safety culture and NRC's regulatory process

The Commission Policy Statement on the Conduct of Nuclear Power Plant Operations [45], makes 'safety culture' part of the NRC's regulatory agenda. Issued in 1989, the policy statement includes the provision that "Management has a duty and obligation to foster the development of a 'safety culture' at each facility and to provide a professional working environment, in the control room and throughout the facility, that assures safe operations." The policy statement then defines safety culture using the definition from INSAG-4.

Current NRC programs to develop risk informed regulatory processes and performance based reactor oversight appear to be in consonance with the idea of some degree of self-regulation. The reactor oversight program [46] identifies a level of performance, as measured by a set of performance indicators, where regulatory involvement will be limited to a baseline inspection program. The program identifies seven cornerstones of safety performance, each monitored by one or more performance indicators. The four cornerstones for reactor safety are initiating events, mitigating systems, barrier integrity and emergency preparedness. In addition to the cornerstones, the staff has identified three 'cross-cutting' elements that are part of each cornerstone. These are human performance, management attention to safety and worker's ability to raise safety issues (safety-conscious work environment), and finding and fixing problems (corrective action programs). There are currently no performance indicators associated with these cross-cutting issues.

The staff recognizes that the new oversight program will involve a shift in the NRC role from improving human reliability to monitoring human reliability. This appears to be consistent with the thought of allowing more of what might be termed 'self-regulation.' On the other hand, the staff equates the term 'safety culture' with 'safety conscious work environment.' This appears to be a much narrower concept of safety culture than is used by most writers in the organizational safety field.

Two questions are suggested here. The first is whether the NRC is giving sufficient attention to the staff skills, knowledge and abilities that will be required in a risk-informed, performance based regulatory scheme. If the NRC is to encourage safety culture, it may require a different perspective on the part of the front-line inspection staff. The second question is whether appropriate attention is being given to identifying performance indicators for human performance, safety culture, or other relevant management and organizational factors.

The ACSNI study group [36] concluded that research is required particularly in two areas. "Firstly, work is necessary simply to increase the number of validated culture and performance indicators available. Secondly, studies are required to establish the extent to which the indicators remain valid once they have been identified and used as indicators."

8. Conclusions

There is a clear consensus among writers in the field of safety management that worker attitudes toward safety make a difference. What is not clear is the mechanism by which attitudes, or safety culture, affect the safety of operations. Statistical evidence that unambiguously links safety culture or specific attributes of safety culture with the safety of operations is surprisingly rare, especially within the nuclear industry.

Pidgeon [47] examines the key theoretical issues underlying the concept of safety culture. He notes that, "...some 10 years on from Chernobyl, the existing empirical attempts to study safety culture and its relationship to organizational outcomes have remained unsystematic, fragmented, and in particular underspecified in theoretical terms." He identifies four theoretical issues that must be addressed if the concept of safety culture is to realize its promise. The first is the paradox that culture can act simultaneously as a precondition for safe operations and an incubator for hazards. The second issue is that in complex and ill-structured risk situations, decision makers are faced not only with the matter of risk, but with fundamental uncertainty characterized by incompleteness of knowledge. The third issue is the organizational construction of acceptable risk. The fourth is the issue of organizational learning and the political need to assign blame for disasters. Pidgeon's paper stresses the importance of safety culture as a concept uniquely capable of improving safety in complex systems.

From the narrow perspective of the nuclear power industry, an important next step in understanding the relationship among safety culture, safety of operations and safety regulation would be to develop consensus on the essential attributes of safety culture and to identify suitable performance indicators. Consensus may not be easily reached, but investigators seem to have made too little use of past work, and constructed new frameworks rather than building on what has been done. Performance indicators will be even more difficult. Some work is underway to determine the degree to which the performance indicators in the reactor oversight program capture human performance issues. The results of that work might provide some insights into how performance indicators could be developed.

The NRC regulatory program must assure that licensee's root-cause analyses and corrective action programs are capable of identifying safety culture issues. Models for human performance, such as ATHEANA [15], will not be realistic until the influence of the plant's safety culture on the 'error-forcing context' is assessed [48].

Ultimately, the NRC will have to arrive at an understanding of how its regulatory process can affect the safety cultures of its licensees, both positively and negatively. The role of the regulator needs to be determined, including the possibility that there is no role other than monitoring.

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